

PATENT APPLICATION
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10 **METHOD AND APPARATUS TO FACILITATE
AUTO-ALIGNMENT OF IMAGES FOR
DEFECT INSPECTION AND DEFECT
ANALYSIS**

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BACKGROUND

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Field of the Invention

[0001] The invention relates to the process of inspecting integrated circuit images. More specifically, the invention relates to a method and an apparatus to facilitate auto-alignment of mask and die images of integrated circuits for defect inspection and/or defect analysis.

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Related Art

[0002] Integrated circuits can be produced through an optical lithography process that involves creating a mask with a pattern specifying where the various

features of the integrated circuit are to be placed and then passing radiation through the mask to expose the pattern on a semiconductor wafer. This pattern defines where the surface of the semiconductor wafer is to be etched or where new material is to be added to create the integrated circuit.

5 **[0003]** As the features of an integrated circuit continue to get smaller, quality control becomes increasingly important in order to ensure that the integrated circuit functions properly. As part of this quality control, integrated circuit manufacturers often compare various images of an integrated circuit; for example, a manufacturer may compare a computer-generated image of the
10 integrated circuit to a mask of the integrated circuit or may compare the mask to a die created from the mask. These comparisons can determine if defects exist and can help determine the cause of these defects.

[0004] These comparisons can be made by first aligning the images being compared and then subtracting, pixel-by-pixel, the reference image from the test
15 image. The resultant difference is ideally zero for all pixels. Differences other than zero may indicate a defect in the test image, which can be analyzed to determine the severity of the defect, and can help determine the cause of the defect. During this defect analysis process, accurate alignment of the images is critical for this process to yield the expected results.

20 **[0005]** Current systems use an auto-correlation method to align these images. Auto-correlation is a very slow process because it requires a computationally intensive mathematical process to be performed pixel-by-pixel on the images. Also, the success rate of auto-correlation is not very high. The auto-correlation algorithm attempts to maximize the correlation coefficient:

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$$c = \frac{\sum (x_{i,j} - \bar{x}) \times \sum (y_{i,j} - \bar{y})}{\left(\sum (x_{i,j} - \bar{x})^2 \right)^{1/2} \times \left(\sum (y_{i,j} - \bar{y})^2 \right)^{1/2}}$$

where $x_{i,j}$ and $y_{i,j}$ are the pixel values of the images at the respective location i and j , and \bar{x} and \bar{y} are the mean values of each image. Thus the auto-correlation algorithm is searching for a location by shifting the two images around to maximize the coefficient. This is an intensive calculation and the range of the shifted positions that are tried will limit the quality of the found position.

[0006] What is needed is a method and an apparatus to facilitate auto-alignment of integrated circuit images for defect inspection and defect analysis that do not exhibit the problems described above.

SUMMARY

[0007] One embodiment of the invention provides a system that facilitates auto-alignment of images for defect inspection and defect analysis. The system operates by first receiving a reference image and a test image. Next, the system creates a horizontal cut line across the reference image. The system then chooses a vertical feature on the reference image with a specified width along the horizontal cut line. Next, the system determines that the vertical feature substantially maintains the specified width over a specified range above and below the horizontal cut line. The system also creates a vertical cut line across the reference image. The system then chooses a horizontal feature on the reference image with the specified width along the vertical cut line. Next, the system determines that the horizontal feature substantially maintains the specified width over a specified range left and right of the vertical cut line. Finally, the system locates the vertical feature and the horizontal feature on the test image so that the reference image and the test image can be aligned to perform defect inspection and defect analysis.

[0008] In one embodiment of the invention, the system creates multiple horizontal cut lines across the reference image and then chooses a horizontal cut

line including at least one vertical feature from these horizontal cut lines. The system also creates multiple vertical cut lines across the reference image and chooses a vertical cut line including at least one horizontal feature from these vertical cut lines. Next, the system creates multiple horizontal cut lines across the test image and chooses a test horizontal cut line by iterating through these horizontal cut lines until the test horizontal cut line includes a test vertical feature with substantially the same horizontal width as the vertical feature and the same neighboring characteristics on the feature, as determined by width. The system also creates multiple vertical cut lines across the test image and chooses a test vertical cut line by iterating through these vertical cut lines until the test vertical cut line includes a test horizontal feature with substantially the same vertical width as the horizontal feature and the same neighboring characteristics. Finally, the system aligns the reference image, and the test image using the horizontal cut line, the test horizontal cut line, the vertical cut line, and the test vertical cut line, and the respective features. As a convenience the cut lines will be referred to although it will be understood that the respective features are being aligned.

[0009] In one embodiment of the invention, the system aligns the reference image and the test image using edges of the vertical feature and the horizontal feature.

[0010] In one embodiment of the invention, the system aligns the reference image and the test image using midpoints of the vertical feature and the horizontal feature.

[0011] In one embodiment of the invention, the reference image includes an inspection mask image generated by mask inspection equipment, a mask image from a database, a wafer image, or a die.

[0012] In one embodiment of the invention, the test image includes an inspection mask image generated by mask inspection equipment, a mask image from a database, a wafer image, or a die.

[0013] In one embodiment of the invention, the system clusters feature widths within the reference image and then chooses a width that occurs most often as the specified width.

BRIEF DESCRIPTION OF THE FIGURES

[0014] FIG. 1 illustrates integrated circuit images in accordance with an embodiment of the invention.

[0015] FIG. 2A illustrates multiple horizontal cuts across an integrated circuit image in accordance with an embodiment of the invention.

[0016] FIG. 2B illustrates width groupings in accordance with an embodiment of the invention.

[0017] FIG. 3 illustrates determining feature width in the neighborhood of a horizontal cut in accordance with an embodiment of the invention.

[0018] FIG. 4 illustrates image aligner 402 in accordance with an embodiment of the invention.

[0019] FIG. 5 is a flowchart illustrating the process of aligning a test image with a reference image in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

Integrated Circuit Images

[0020] FIG. 1 illustrates integrated circuit images in accordance with an embodiment of the invention. Reference image 102 and test image 104 include the same features of an integrated circuit, however, their sizes may not be identical, as shown. Reference image 102 may be a computer-generated image

generated from a GDS-II description or other system description of the layout, a mask image, or a wafer image used for comparison with test image 104. Test image 104 may also be a computer-generated image, a mask image, or a wafer image used for comparison with reference image 102, and may include defects such as defect 114.

[0021] In operation, the system places horizontal and vertical cut lines on reference image 102. FIG. 1 illustrates horizontal cut line 106 and vertical cut line 108 on reference image 102. The system also places horizontal and vertical cut lines on test image 104. FIG. 1 illustrates horizontal cut line 110 and vertical cut line 112 on test image 104. The system aligns reference image 102 and test image 104 by locating the same features using horizontal cut lines 106 and 110 and vertical cut lines 108 and 112. Once aligned, the system can compute the difference between reference image 102 and test image 104 for defect analysis. For example, defect 114 could be identified and reported to a user of the software tool, e.g. by visually highlighting the area, generating an error report, etc. The user might then simulate the region with the defect using a tool such as the Virtual Stepper® to determine if a particular mask error should be reported. Virtual Stepper® is a registered trademark of Numerical Technologies, Inc. of San Jose, CA. Determining if a particular mask error should be reported can involve defect severity scoring. Inspection, severity scoring, and mask error reporting are described in more detail in U.S. Patent Applications Serial No. 09/130,996, entitled "Visual Inspection and Verification System," by Fang-Cheng Chang, et al, filed August 7, 1998, which is hereby incorporated by reference; Serial No. 09/815,023, entitled "System and Method of Providing Mask Quality Control," by Lynn Cai, et al, filed March 20, 2001, which is hereby incorporated by reference; and Serial No. 09/815,025, entitled "System and Method of Providing Mask

Defect Printability Analysis,” by Lynn Cai, et al, filed March 20, 2001, which is hereby incorporated by reference.

Using Multiple Cut Lines

5 [0022] FIG. 2A illustrates multiple horizontal cuts across an integrated circuit image in accordance with an embodiment of the invention. Note that this integrated circuit image can be either reference image 102 or test image 104. Cut lines 208, 210, 212, and 214 have been placed across image features 202, 204, and 206. More specifically, cut line 208 crosses feature 204 at point A; cut line 210 crosses features 202 and 204 at points B and C, respectively; cut line 212 crosses features 202, 204, and 206 at points D, E, and F, respectively; and cut line 214 crosses features 202 and 206 at points G and H, respectively. More or fewer cut lines can be used. The same procedures and discussions apply equally to vertical cut lines so no further discussion of vertical cut lines will be included herein.

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15 After cut lines have been placed across the image, the crossing points are grouped according to width.

 [0023] FIG. 2B illustrates width groupings in accordance with an embodiment of the invention. Feature 202 has a nominal width between 95 and 110 nm; feature 204 has a nominal width between 90 and 95 nm; and feature 206 has a nominal width between 110 and 130 nm. As shown in grouping chart 216, points A, C, and E are grouped together with a nominal width of 90-95 nm; points B, D, and G are grouped together with a nominal width of 95-110 nm; and points F and H are grouped together with a nominal width of 110-130 nm. The system selects a feature with the selected width from one of the groups in grouping chart

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25 216, for example feature 202 at point D. In one embodiment, the chosen point is a feature having median width. In another embodiment the chosen point is a feature having a width that occurs most often. Next, the system determines if the width is

substantially constant within a specified range from point D as described below in conjunction with FIG. 3. If the width is not substantially constant, the system selects a different point before continuing. The next point can be from within the same width group or another point with a different width, e.g. point F. A

5 substantially constant width is used to avoid corners and defect locations and to assure better alignment results. If no points are found that work, the criteria for the range above and below the points can be lowered. If still no points are found, the alignment fails.

10 **Determining Feature Width**

[0024] FIG. 3 illustrates the process of determining feature width in the neighborhood of a horizontal cut in accordance with an embodiment of the invention. The system determines the width at several points on feature 202 about cut line 212 between limits 302 and 304. Limits 302 and 304 are selected to give

15 assurance that feature 202 has a substantially constant width and that the selected point can be used to make a valid comparison between reference image 102 and test image 104. After determining that the selected point on reference image 102 can be used to make a valid comparison, the system attempts to locate the equivalent point on test image 104 as described below in conjunction with FIG. 5.

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Image Aligner

[0025] FIG. 4 illustrates image aligner 402 in accordance with an embodiment of the invention. Image aligner 402 includes image receiver 404, cut line generator 406, feature width clusterer 408, feature chooser 410, width checker

25 412, feature matcher 414, and image alignment mechanism 416. Image receiver 404 receives reference image 102 and test image 104 for alignment. Cut line

generator 406 creates both horizontal and vertical cut lines across reference image 102 and test image 104 as described above in reference to FIGs. 1-3.

5 [0026] After cut line generator 406 creates cut lines across reference image 102 and test image 104, feature width clusterer 408 classifies each feature according to width and sorts the features into groups as described above in conjunction with FIG. 2A. Feature chooser 410 then selects a feature for comparison as described below in conjunction with FIG. 5.

10 [0027] Width checker 412 checks the width of the feature chosen by feature chooser 410 to ensure that the width of the chosen feature remains substantially constant over a small range near the cut line by stepping small increments in both directions from the cut line and comparing the feature width with the feature width at the cut line.

15 [0028] After features have been chosen on both horizontal and vertical cut lines, feature matcher 414 matches the features on test image 104 to match the selected features on reference image 102. A feature on the test image can be said to be matched with a feature on the reference image if (1) it has substantially the same width and (2) substantially the same neighborhood properties as the feature on the reference image. In one embodiment, the tolerance is allowed to compensate for slightly different image sizes, e.g. plus-or-minus ten percent.
20 When matching features have been found on both reference image 102 and test image 104, image alignment mechanism 416 aligns these images for subtraction and subsequent defect inspection and analysis.

Aligning the Images

25 [0029] FIG. 5 is a flowchart illustrating the process of aligning a test image with a reference image in accordance with an embodiment of the invention. The system starts by receiving reference image 102 and test image 104 (step 502).

Next, the system places multiple cut lines through reference image 102 (step 504). The system then measures the width of the features on the cut lines (step 506).

5 **[0030]** After measuring the width of the features, the system groups the measured width values into buckets sorted according to size (step 508). Next, the system selects a feature with a width that occurs most often from the measured width values (step 510). The system then ensures that the width is substantially constant near the selected cut line by iterating about the cut line in small increments (step 512). If the width is not substantially the same, a new point is selected.

10 **[0031]** After selecting a point on reference image 102, the system locates the same feature on test image 104 (step 514). Next, the system ensures that the cut line has the same features near the selected feature to determine that the features are the same (step 516). Finally, the system aligns the edges of the feature on both images (step 518). The system can also align the midpoints of the
15 feature. Note that the same process is followed to align the images using the vertical cut lines for the vertical direction alignment. After both directions are aligned, the images are aligned.

20 **[0032]** The preceding description is presented to enable one to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the invention. Thus, the invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and
25 features disclosed herein.

[0033] The data structures and code described in this detailed description are typically stored on a computer readable storage medium, which may be any

device or medium that can store code and/or data for use by a computer system. This includes, but is not limited to, magnetic and optical storage devices such as disk drives, magnetic tape, CDs (compact discs) and DVDs (digital versatile discs or digital video discs), and computer instruction signals embodied in a
5 transmission medium (with or without a carrier wave upon which the signals are modulated). For example, the transmission medium may include a communications network, such as the Internet.

[0034] The foregoing descriptions of embodiments of the invention have been presented for purposes of illustration and description only. They are not
10 intended to be exhaustive or to limit the invention to the forms disclosed. The scope of the invention is defined by the appended claims.